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Reducing Mortality on the Fortymile Caribou Herd

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This is a progress report on continuing research. Information may be refined at a later date. Some figures are not included in the electronic version of this report.

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SUMMARY

This is the first of 5 research reports to be written on reducing mortality of the Fortymile caribou (*Rangifer tarandus granti*) herd. This report also summarizes work completed during the prior 5 years on factors limiting the Fortymile herd. The research proposal for reducing mortality on the Fortymile herd was inspired by a diverse, international Fortymile Planning Team through their Fortymile Caribou Herd Management Plan (Boertje and Gardner 1996:Appendix A; http://aurora.ak.blm.gov/fmcaribou/). The Board of Game endorsed the Team's novel management plan in October 1995, and 10 independent scientists reviewed the draft research proposal for this project in winter 1995–1996.

The primary goal of the Team's plan is to begin restoring the Fortymile herd to its former range, much of which was abandoned as herd size declined. Specific objectives call for increasing the herd at least 5–10% annually from 1997–1998 through 2001–2002. The herd grew 20% between late June 1997 (25,910) and late June 1998 (31,029).

Since 1994, intensive monitoring of radio collars on newborn and older caribou allowed investigations of caribou productivity and mortality. These data enabled us to complete 4 annual models illustrating how predation and other demographic factors affected herd size from mid May 1994 through early May 1998.

We identified wolf (*Canis lupus*) predation as a major limiting factor in all 4 annual models (1994–1997). Reducing wolf predation was deemed by the Team to be the most manageable way to help hasten or stimulate herd growth. The Team envisioned 2 strategies for reducing wolf predation: first, state-sponsored wolf translocations and fertility control in 15 key packs and, second, shifting private wolf trappers to specific areas. The number of wolf packs preying on Fortymile caribou ranged from 26–37 in recent years, but most of the wolf predation occurred within the range of the 15 packs proposed for treatment. We regularly radiotracked wolves in 16 to 22 packs annually since 1992 to help estimate wolf numbers in the herd's range.

Management actions began in autumn 1996 with a reduction in the harvest from ≤2% of the herd to <1% of the herd (150 bulls) for 5 years. This action was taken to increase the social acceptance of the plan. A privately sponsored incentive program for trappers during 2 winters helped significantly increase the wolf harvest rate above recent levels in winter 1995–1996, but not in winter 1996–1997. In spring 1997 the Board of Game approved a detailed agency plan for reducing wolf predation. We began actions to reduce wolf predation on Fortymile caribou in late November 1997. Seven key wolf packs were reduced 84% from 61 wolves in autumn 1997 to 10 wolves in April 1998. We translocated 31 wolves, 17 were harvested by private trappers/hunters, and 4 died from other causes. We also sterilized wolves in 5 of these key packs to prevent production in May 1998. It is too early to evaluate the effects of this treatment on wolves or caribou. When 15 total packs are treated, we hope to evaluate the effects of treatment on reducing wolf predation on radiocollared calves.

The following points will assist with continuing efforts to evaluate management objectives proposed by the Fortymile Planning Team:

1 Herd numbers remained relatively stable during 1990–1995 (22,000–23,000 caribou) prior to and during formulation of the Fortymile Caribou Herd Management Plan. Relatively stable herd size resulted from high adult mortality during 1989–1992 (17–40%), unusually poor pregnancy rate in 1993 (68%), and low to moderate calf:cow ratios in autumn 1989–1994 (16–30).
In contrast, we counted 4% more caribou in 1996, 10% in 1997, and 20% in 1998. Our latest count of the herd on 28 June 1998 totaled 31,029. Annual increases in the herd since 1995 resulted from several factors including elevated pregnancy rates in 1996 and 1998 (97–98%), improved adult survival rates compared to those in the early 1990s, and improved calf survival rates, particularly in 1997. Hence, both optimal environmental conditions and reduced predation contributed to the herd's increase. The Team deemed that initiating and continuing management actions to improve caribou survival during a period of optimal weather and natural increase would be opportune.

2 Wolf and grizzly bear (*Ursus arctos*) predation have been the most important sources of mortality, despite over a decade of the most liberal regulations in the state for harvesting wolves and grizzly bears. Wolves have been the most important predator. Wolves killed between 2000 and 3000 caribou calves annually during 1994–1997 and between 1000 and 2300 older caribou. We observed no significant differences in annual wolf predation rates on radiocollared calves or adults between May 1994 and May 1998.

We have ceased plans to translocate grizzly bears. The Fortymile Caribou Herd Management Plan proposed translocating grizzly bears from the calving grounds during May 2001 if increased May grizzly bear predation compensated for expected decreased May wolf predation. However, May grizzly bear predation did not increase in 1997 or 1998 when May wolf predation declined compared to predation during 1994–1996.

3 To increase social acceptance of the management plan, the Fortymile Team chose to reduce the annual caribou harvest to 150 bulls for 5 years beginning in 1996. We illustrated the minor role that harvest has played in herd dynamics in recent years. Harvests have been intentionally held low since 1973 to encourage herd growth (Valkenburg et al. 1994). Reducing harvests from 200–500 bulls (≤2% of the herd, 1990–1995) to 150 bulls (<1% bulls, 1996–2000) will not result in the 5–10% annual rates of herd increase desired by the Fortymile Team. Bull:cow ratios in the Fortymile herd ($\bar{x}$ = 43 bulls:100 cows, range = 36–50, 1985–1997) are not reduced by harvest compared to ratios from the only Interior Alaska herd with no harvest in recent decades ($\bar{x}$ = 43 bulls:100 cows, range = 29–56 in the Denali herd, 1985–1997).

4 Despite private efforts that significantly increased wolf harvest above recent levels during winter 1995–1996, autumn wolf densities on the respective annual ranges of the Fortymile herd remained at densities (6–8 wolves/1000 km^2) often observed in Alaska–Yukon study areas with similar low prey densities and low wolf harvest rates. Only strong reductions in autumn wolf densities (≥69%) have been followed by rapid increases in caribou numbers (Boertje et al. 1996).

5 We found consistent evidence for moderate to high nutritional status in the Fortymile herd since 1994 when indices were compared with other Alaskan herds (Whitten et al. 1992; Valkenburg 1997). The single evidence for malnutrition was the low pregnancy rate during 1993 following the abnormally short growing season of 1992. Elevated pregnancy rates in 1996 and 1998 and elevated bodyweights of 5-month-old calves in 1997 clearly indicate improved environmental conditions beginning in summer 1995. Antibody screening of blood samples (n = 159) collected since 1980 indicates no significant infectious diseases are affecting the population dynamics of the Fortymile herd.

6 Winter range can support elevated caribou numbers in regard to lichen availability on currently used winter range and the availability of vast expanses of winter range formerly used by the herd. The herd currently uses <30% of its historic range and winter fecal analyses indicate the herd consumes a high proportion of lichens compared to several other herds (80% lichen fragments in winter feces). Lichens are often the first forage to show signs of overgrazing because lichens grow slowly and are highly desired by caribou.

We will continue studies of Fortymile calf mortality from 1998–2002 by deploying radio collars on newborns. These studies will allow evaluation of whether reduced wolf numbers in the treatment area result in significantly reduced wolf predation on calves. Treatment of 15 key wolf packs is planned from May 1999 through May 2001. During these 2 years, we will test whether wolf predation on calves is significantly reduced compared to the 3 pretreatment years (May 1994–May 1997) when wolves killed 13–19 (25–30%) of 50–60 radiocollared calves. The interim 2 years (May 1997–May1999) will be partially treated.

Key words: Alaska, caribou, condition, fertility control, Fortymile caribou herd, management objectives, mortality, nutrition, predation, pregnancy rate, translocation, sterilization, wolf.

CONTENTS

BACKGROUND

The Fortymile caribou herd has the potential to be the most economically important wildlife population in Interior Alaska and the southern Yukon, both for consumptive and nonconsumptive uses. Potential for growth is indicated by Murie's (1935) extrapolated estimate of 568,000 caribou during a 20-day herd migration across the Steese Highway in 1920, compared to an aerial photocensus of 31,029 caribou on 28 June 1998. The herd’s low point was in summer 1973 with about 7000 caribou (Valkenburg et al. 1994).

Caribou herds typically restrict range use as herd size declines. For example, the Fortymile herd has not migrated across the Steese Highway since 1963 and rarely enters the Yukon because of its reduced size. The herd's historical range encompassed 220,000 km^2 (Murie 1935) compared with about 50,000 km^2 total for all years since 1968 (Valkenburg et al. 1994; Fig 1) and 23,000 km^2 to 35,000 km^2 annually in recent years. Today, the historical range of the herd is largely devoid of caribou.

Population objectives for increasing the Fortymile caribou herd have wide public support in Alaska and the Yukon for consumptive and nonconsumptive reasons. This public support has developed because most of the herd's former range was abandoned as herd size declined and because current low numbers are, in part, a result of past management decisions.

We have learned much from past management of the Fortymile herd. Valkenburg et al. (1994) detailed a case history of the herd from 1920 to 1990. The decline in the herd from >50,000 in 1960 to only 7000 in summer 1973 was partly a result of errors in the prevailing management beliefs. Overharvest was allowed in the early 1970s, and, simultaneously, high numbers of wolves and unfavorable weather contributed to the herd's decline to critically low levels (Davis et al. 1978; Valkenburg and Davis 1989; Valkenburg et al. 1994). Had this overharvest been prevented, the herd probably would have declined to only 10,000–20,000 caribou during the early 1970s and may have increased to 30,000–50,000 during favorable conditions in the 1980s.

Overharvest was allowed in the early 1970s in part because of the belief that poor range condition was the major factor causing low yearling recruitment. Thus, biologists allowed high harvests and largely ignored wolf predation while awaiting a compensatory rebound in yearling recruitment from improved range. However, it was a futile vigil; calf caribou became increasingly scarce through 1973. It was mistakenly believed hunters and predators usually killed animals that were about to die anyway (before successfully reproducing) and wolf and grizzly bear predation were minor influences on the herd. Also, the size of the Fortymile herd was grossly overestimated during the decline to 7000 caribou and the trend in herd size inadequately monitored (Davis et al. 1978; Valkenburg and Davis 1989).

Today harvest programs for caribou are managed much more conservatively than in the early 1970s. During natural declines of caribou to low levels, harvests are eliminated or restricted to small percentages of bulls and carefully monitored using permit systems. Since 1973, substantial reductions in the human harvest of Fortymile caribou have made harvest an insignificant factor affecting herd growth compared to predation by wolves and bears

(Valkenburg et al. 1994; Appendices A, B, C and D). Since 1984 radiocollaring Fortymile caribou has given biologists the ability to efficiently estimate herd distribution to predict hunter success, particularly along roads. Other benefits from radiocollaring include efficient estimates of herd size, proportions of calves and bulls, mortality rates, causes of mortality, and relative nutritional status (Valkenburg and Davis 1989; Valkenburg et al. 1994; Valkenburg 1997).

Today managers know adverse weather can initiate declines in caribou herds (Valkenburg et al. 1994; Adams et al. 1995*a*; Boertje et al. 1996). Adverse weather in Interior Alaska in the early 1990s and the simultaneous decline of several Interior caribou herds were, in part, the stimuli for this renewed study of the Fortymile herd. During periods of adverse weather, herd condition can decline and predation can increase (Mech et al. 1995; Boertje et al. 1996). After weather improves, prolonged declines in caribou herds can occur from continued high wolf predation probably because of wolves' switching to caribou as primary prey and because declines in wolf numbers are not tied strictly to caribou numbers and can lag behind declines in total caribou numbers (predator lag). We know of examples in which the proportion of a herd killed by wolves increased during adverse weather because caribou were more vulnerable and because wolf numbers increased as caribou declined (Adams et al. 1995*a*; Mech et al. 1995; Boertje et al. 1996).

Today it is a well-accepted belief that wolf and bear predation are often the major factors limiting caribou and moose (*Alces alces*) at low densities (Davis et al. 1978, 1983; Gasaway et al. 1983, 1992; Boertje et al. 1987, 1988; Larsen et al. 1989; Valkenburg and Davis 1989; Adams et al. 1995*b*; Boertje et al. 1996). Several studies summarized historical and recent predator–prey relationships in the Fortymile area and documented that predation was a major factor limiting recovery of caribou and moose populations (Davis et al. 1978; Boertje et al. 1987, 1988; Valkenburg and Davis 1989; Gasaway et al. 1992).

From 1981 through 1987, management actions were implemented to reduce grizzly bear and wolf predation in a portion of the Fortymile herd's range (Valkenburg and Davis 1989; Gasaway et al. 1992). Control of wolf numbers by department personnel was terminated before desired reductions were achieved, and grizzly bear numbers were only moderately reduced in a small portion of the range. Subsequently 7–10% annual increases in caribou numbers could not be definitively linked to predator control because pretreatment studies were lacking and only small reductions in predator abundance occurred in the annual range of the Fortymile herd (Valkenburg et al. 1994). Increased harvests of wolves and grizzly bears in the 1980s were insufficient to allow for herd growth during 1990–1995, presumably because of adverse weather and insufficient reduction of predators.

To definitively test the effectiveness of predator control, large reductions in predator abundance are necessary for several years (Crete and Jolicoeur 1987; Larsen and Ward 1995; Boertje et al. 1996; Farnell and Hayes, unpubl data). Large reductions in wolf numbers for several years resulted in dramatic increases in caribou numbers in central Alaska (16% per year; Gasaway et al. 1983; Boertje et al. 1996) and eastcentral Yukon (18% per year; Farnell and MacDonald 1988; Larsen and Ward 1995; Farnell and Hayes, unpubl data). In both studies, late winter wolf numbers were 69–85% lower than precontrol autumn wolf numbers during the 4 to 6 winters of effective control efforts. These are the only well-documented studies in which large reductions of wolves were maintained for more than 2 winters and wolves were subsequently allowed to recover.

MANAGEMENT PLANNING, OBJECTIVES, RATIONALE, AND PRESENTATIONS

International draft management objectives from the mid-1980s through 1995 called for increasing the herd to 50,000 adults or 60,000 caribou by the year 2000. These management objectives were written when the herd was growing at 7–10% per year and when we expected to reach these population objectives without further management actions. Instead, herd numbers were nearly stable between 1990 and 1995 at about 22,500 caribou.

Conflicting interagency management objectives by 1994 stimulated an interagency and international meeting focusing on Fortymile herd management in Tok on 9 February 1994. Following this meeting, a diverse Fortymile Planning Team was created to write a new Fortymile Caribou Herd Management Plan (Boertje and Gardner 1996:56–77). This novel plan was completed and endorsed by the Board of Game in October 1995. The Team met 8 times between autumn 1994 and autumn 1995 to develop the plan and continues to meet to address issues of importance. Ten public meetings were held in various places to gather public opinion on the plan. The Board of Game approved a detailed implementation plan for the Fortymile Caribou Herd Management Plan in spring 1997, and we began implementation (wolf fertility control and translocations) in November 1997. We drafted the current 5-year research plan in 1995 for the years 1997–2002 (Boertje and Gardner 1996:Appendix A:28–56). This research plan was edited by 10 independent, international scientists familiar with wolf biology and predator–prey relationships in winter 1995–1996.

The Team described reasons for developing a recovery plan for the Fortymile herd as follows (Boertje and Gardner 1996:Appendix A:31, 33):

- For the long-term benefit of the Fortymile ecosystem and, specifically, the biodiversity of this ecosystem.
- Help recover the Fortymile caribou herd to its traditional range and to benefit the people who value the herd and its ecosystem.
- Promote viewing opportunities of the Fortymile herd during its spring and fall migrations, particularly along the Steese, Taylor, Top of the World, and Klondike highways where people once witnessed thousands of migrating caribou.
- Promote similar goals among the agencies involved in management of the Fortymile caribou herd.
- Resolve conflicts among interest groups.
- Encourage sound wildlife management decisions that consider diverse values.

The primary goal of the new Fortymile Caribou Herd Management Plan is to restore the Fortymile herd to its former range, which entails initiating management actions to increase herd size. Specific objectives include increasing caribou numbers by at least 5–10% per year through the year 2002 using primarily nonlethal techniques to control wolf predation. The Wolf Conservation Management Policy for Alaska (see 5 AAC 92.110) directs the Alaska Department of Fish and Game to investigate nonlethal means of reducing predation.

In the following paragraphs, we describe the various management actions and rationale proposed by the Fortymile Team.

- The nonlethal program recommended by the Team includes translocating (i.e., moving) wolves other than dominant pairs and controlling fertility among dominant pairs in up to 15 key packs during 4 winters (1997–1998, 1998–1999, 1999–2000, and 2000–2001). We will initially treat up to 7 new packs per winter. A site-based approach will be taken with the highest priority given to packs expected to be near newborn caribou, but wolves will have to be treated in the winter because of logistical problems in handling wolves without fresh snow. A further complication is that calving distribution changes annually in the Fortymile herd. Also, we will treat only a portion of the packs that prey on caribou calves. For instance, 26 to 37 wolf packs fed on Fortymile caribou during recent years and at least 3 important packs live primarily in the Yukon–Charley Rivers National Preserve.

Mech et al. (1995) suggested fertility control in wolves may be preferable to lethal agency control for several reasons. Ethical and political objections to lethal wolf control by government agencies are significant (Mech 1995, Boertje et al. 1995*b*, Stephenson et al. 1995). With winter wolf harvest rates of $<60\%$, a wolf territory is often filled in spring by a pregnant female with high spring and summer food requirements (Hayes 1995). In contrast, the absence of a litter of pups can reduce a pair's need for food by 40–60% in summer (Mech 1970, 1977). Also, vasectomizing males in 4 wolf packs in Minnesota and 1 in the Yukon resulted in stable or decreased pack size and retention of territories (n = 18 pack-years of data; Mech et al. 1996; RD Hayes, pers commun).

- Harvest quotas for caribou will be reduced from 450 bulls in 1995 to 150 bulls during autumn 1996–2000. Biological ramifications of this action are predicted to be small, but representatives of hunting groups on the Team sanctioned reduced caribou harvest to increase the social acceptance of the plan. Social acceptance of the management plan is vital to its implementation.

- The Team stated in the plan that local trappers could assist by shifting their efforts to wolves whose territories include the summer range of the Fortymile herd, where few wolves were being trapped.

Herd response to these management actions will depend largely on changes in wolf and bear predation, weather, and caribou distribution and productivity. Thus, response to the proposed management actions could vary considerably among years.

For several reasons, multiple, simultaneous actions were chosen to attempt to increase Fortymile Herd size. Foremost, the Team preferred a consistent moderate to high annual growth rate (≥5–10%); this growth rate will be required to convince a broad scientific audience that proposed actions were indeed effective. For example, biologists have occasionally observed natural annual growth rates of 7% in the Fortymile herd (Valkenburg et al. 1994) and the Denali herd (Adams et al. 1995*a*), so a higher rate will be needed for several years to convince a broad scientific audience that a particular treatment was effective.

Based on previous research and modeling (Boertje et al. 1995*a,b*), the chances of significantly increasing herd size are small if only single nonlethal actions are used to reduce predation. In the case of the Fortymile herd, single actions are unlikely to be effective because no nonlethal treatment will occur on the central portion of the summer range, the Yukon-Charley Rivers National Preserve, or on much of the surrounding winter range. Relating cause and effect is difficult in natural systems and requires gathering support for a particular hypothesis over many years and study areas. No simple procedure exists for "proving" the proposed actions will reliably and significantly increase caribou numbers.

After the summer 2002 photocensus of the herd, results will be evaluated to determine public acceptance and the costs and effectiveness of the management actions. We presented our findings to date in 6 editions of *The Comeback Trail*; a newsletter written to inform the public and agencies of Fortymile herd planning, management, and research. This newsletter is published by the Alaska Department of Fish and Game and mailed to 3300 interested parties to solicit their opinions. We also assisted Northern Native Broadcasting of Whitehorse in the production of a 52-minute documentary video on Fortymile herd history, planning, and biology. This video was released in January 1998.

This report provides the 5-year baseline pretreatment data for the study area and data from the first winter of partial treatment. It is too early to test whether wolf reductions in 7 packs during winter 1997–1998 resulted in significantly improved calf survival in the 1997 and 1998 cohorts.

GOAL

Our goal is to evaluate the effects of the above-proposed management actions on both caribou and wolves, and, secondarily, to evaluate the effects on moose and Dall sheep (*Ovis dalli*).

JOB OBJECTIVES

LITERATURE REVIEW

We will continue a literature review of wolf translocations; canid fertility control; responses of caribou and moose to reduced predation; ecology and interactions of these predators and prey; nonlethal techniques for reducing predation; and effects of harvest on wolves, bears, and caribou.

CARIBOU

As wolf numbers are reduced, we will continue to model Fortymile caribou herd production and causes and rate of mortality to annually evaluate effects of wolf-caused mortality on herd trend. Data will be compared with data from pretreatment years (1994–1996).

WOLVES

Wolf fertility control and translocations are scheduled for 4 consecutive winters (1997–1998, 1998–1999, 1999–2000, and 2000–2001) and will involve sterilizing adult pairs and translocating the remaining wolves in no more than 15 packs.

Using radiotelemetry, we will monitor distribution and numbers of wolves in treated and several adjacent untreated packs during this study. Our hypothesis is that sterilization will not reduce the chance of maintaining a territory or increase the probability of dispersal, as previously observed in smaller study samples by Mech et al. (1996) in Minnesota and RD Hayes (pers commun) in the Yukon. To ensure that sterilization does not interfere with gonadal cycling, males will be vasectomized by surgical techniques (Pineda and Hepler 1981). Females will be tubally ligated. A qualified veterinary surgeon will conduct the surgical sterilizations.

We will monitor survival rates and homing abilities of translocated wolves to determine if young, translocated wolves regularly succumb near release sites, return to or attempt to return to capture sites, or disperse widely from release sites (Fritts et al. 1985). Fritts et al. (1985) concluded that survival of translocated wolves was comparable to that of other wolves and that pup wolves remained at release sites longer and had poorly developed homing abilities compared to those of adults. We will test these hypotheses using similar techniques. Wolf translocation and moving procedures will follow those of Fritts et al. (1984) in Minnesota with the following exceptions: 1) most wolves will be moved from October through June, but no wolves <5 months old will be moved, and 2) all wolves will be moved at least 100 miles (160 km) because of homing tendencies. Release sites will have prey densities greater than or equal to prey densities in the Fortymile range.

We will estimate wolf harvest rates in the respective annual ranges of the Fortymile caribou herd to monitor effects of harvests, translocations, and sterilizations on wolf numbers.

GRIZZLY BEARS

Objectives for grizzly bears have been deleted from this study because conditions for their study, as described in the research proposal, have not been met. The Fortymile Team proposed translocating grizzly bears from the caribou calving grounds during May 2001 if grizzly bears increased their predation rates on May calves in response to expected decreased wolf predation on May calves. However, May grizzly bear predation did not increase to ≥15% in 1998 following decreased May wolf predation. Also, May grizzly bear predation did not increase in 1997 following significantly reduced May wolf predation relative to 1994–1996.

MOOSE

We will document whether a significant increase in moose density occurs in the treatment area between October 1998 and October 2002 compared to adjacent untreated areas.

In keeping with the Team's goal of benefiting the biodiversity of the Fortymile ecosystem, we will survey moose before and after treatment to evaluate effects of the treatment on moose. Our 10-year objective will be to document whether moose increase to above the low-density dynamic equilibrium (0.1–1.0 moose/1000 km^2) described for this wolf–bear–moose–caribou–human system when predators are lightly harvested (Gasaway et al. 1992).

DALL SHEEP

We will document whether significant increases in sheep numbers occur in the treatment area between 1997 and 2002 compared to nearby untreated areas.

We will survey sheep before (1997) and after (2002) treatment to document whether sheep increase during the period of wolf reductions in the treatment area. Data in the treatment area will be compared to data collected in adjacent untreated populations within the Yukon–Charley Rivers National Preserve. We will test the hypothesis that significant increases in sheep will occur if wolf numbers are reduced.

PUBLIC INVOLVEMENT AND AWARENESS

We will write progress reports, publish a final report, and incorporate results in future plans. The final report for the previous 5-year study was presented at the Eighth North American Caribou Workshop in Whitehorse in April 1998 and will be published as part of these proceedings. We will continue to publish *The Comeback Trail* newsletter, which presents information on the Fortymile herd. We will continue to present findings at pertinent public meetings. Additional guidelines are presented on page 39 of the Fortymile Caribou Herd Management Plan (Boertje and Gardner 1996).

PROCEDURES

CARIBOU CAPTURE

We have radiocollared 49 adults and 129 autumn calves since September 1990. Each autumn we collared 14 or 15 calves. Adults were collared in 1991, 1992, 1996, and 1997 to provide a sample of productive, older caribou. Blood samples and body measurements were routinely collected. Radio collars transmitted for 6 or 7 years (Telonics, Mesa, Arizona, USA and Advanced Telemetry Systems, Isanti, Minnesota, USA).

To immobilize adult caribou, we used 3 mg carfentanil citrate (3 mg/ml, Wildnil®, Wildlife Pharmaceuticals, Fort Collins, Colorado, USA) and 100 mg xylazine hydrochloride

(100 mg/ml, Anased®, Lloyd Laboratories, Shenandoah, Iowa, USA), administered in a 2-cc dart with a 1.9-cm barbed needle. We used a short-range Cap-Chur pistol, fired from a Robinson R-22 helicopter. To reverse the immobilization, we injected 275 mg naltrexone hydrochloride (50 mg/ml, Trexonil®, Wildlife Pharmaceuticals) and 27.5 mg yohimbine hydrochloride (5 mg/ml, Antagonil®, Wildlife Pharmaceuticals) intramuscularly. We immobilized autumn calves with 1 mg carfentanil citrate and 67 mg xylazine hydrochloride reversed with 125 mg naltrexone hydrochloride and 12.5 mg yohimbine hydrochloride intramuscularly.

We radiocollared 50 newborn calves in May 1994, 52 in May 1995, 60 in May 1996, 55 in May 1997, and 72 in May 1998. We used a 2-person, Robinson R–22 helicopter. Usually a person was dropped off to capture the calf by hand, but occasionally we used the helicopter to slowly herd the cow and calf toward the hidden person. Most calves selected for collaring had a collared dam, and we distributed the remaining collars both geographically and temporally to mimic the calving of collared dams. Handling took <1.5 minutes/calf. Expandable, breakaway radio collars transmitted for about 17 months.

ESTIMATING HERD NUMBERS AND GROWTH RATE FROM PHOTOCENSUSES

We estimated minimum numbers of Fortymile caribou between 14 June and 1 July 1990, 1992, and 1994 through 1998 using radio search, total search, and aerial photo techniques (Valkenburg et al. 1985), as in previous estimates of herd size during the 1970s and 1980s (Valkenburg and Davis 1989). The entire summer range was divided among observers in 4 or 5 light aircraft during a 1-day census. These aircraft and a separate radiotracking plane communicated locations of caribou groups to the pilot of a DeHavilland Beaver aircraft equipped with a 9x9 format camera. This camera was used to photograph all groups numbering over 100 caribou; usually 10 to 30 groups were photographed during a census. Smaller groups (<100 caribou) were often visually counted. The number of caribou visually counted from the spotter planes totaled about 500 caribou annually. Photographed caribou were counted using 10X magnification under bright lights. Counts probably include a high proportion of the total calves, but we are certain some calves are missed because of their small size and because of varying photo quality. We suspect that a fairly consistent proportion of the calves are counted among years; but because counters cannot consistently separate calves from adults in the photos, we have no way of testing this hypothesis.

To date we have used photocensus data to calculate growth rates of the herd (Boertje et al. 1996). We also used data on herd composition, pregnancy, and mortality to model population trends because photocensuses have, on occasion, substantially underestimated caribou numbers in the Delta herd (Boertje et al. 1996).

EXPLAINING CAUSES FOR HERD FLUCTUATIONS AND ESTIMATING TREND FROM DATA ON HERD COMPOSITION, PREGNANCY, AND MORTALITY

We developed simple conceptual models to assess how productivity and various mortality factors affected herd size among years. Data on herd composition and total numbers allowed us to calculate the number of potentially productive cows in the herd, i.e., cows ≥36 months old (Appendices A, B, C, and D). We then calculated the number of calves born (pregnancy rate x number of cows ≥36 months old). Finally, using proportions of mortalities among collared samples, we calculated the number of calves and adults dying from various causes. This allowed us to calculate net recruitment (number of calves surviving 12 months minus the number of adults dying during those 12 months).

To estimate herd composition, we classified caribou from a helicopter during late September or early October 1991–1997, using the distribution of radiocollared caribou to randomly select caribou for counting. Cows, calves, and small, medium, and large bulls were counted during the 1-day survey each year. Caribou bulls and cows are more randomly mixed during this period than during the remainder of the year. The helicopter crew relied on a Bellanca Scout pilot to relay locations of radiocollared caribou. After each count, we verified that the proportion of caribou counted in an area closely matched the proportion of radio collars in that area, and we corrected biases in the counts using ratios when necessary.

We estimated pregnancy rates of the herd during mid to late May by documenting the presence or absence of a calf, hard antlers, and a distended udder among radiocollared female caribou ≥24 months old (Whitten 1995). Pregnancy was easy to confirm using these techniques. To confirm nonpregnancy, we repeated observations at least twice during 11–31 May 1984–1998.

We estimated mortality rates among different age classes from October 1992 to October 1997 by radiolocating all collared caribou 1 or 2 times monthly. In addition, from 1994 through 1997, we flew daily between 11 May and 31 May, 10–13 times in June, and weekly during July through September. Radio collars contained a mortality sensor that doubled the pulse rate if the collar remained motionless for 1 or 2 hours (newborn calf collars) or 6–10 hours (other collars). Annual mortality rate (M) was calculated as $M = A/B \times 100$, where A = the number of caribou dying during the 12-month period and B = the total number of collared caribou at the beginning of the 12-month period. We used the chi-square test of proportions to test for statistical differences among proportions (Conover 1980:144–151).

EVALUATING CAUSES OF NATURAL CARIBOU MORTALITY

When a mortality was detected during daily May flights, we investigated the site by helicopter, usually within 4 hours of detection. After May we investigated mortality sites as soon as possible, usually within 1 day of detection. We necropsied carcasses either on-site or in the laboratory and noted wounding patterns. Hemorrhaging associated with puncture wounds, blood (noncoagulated) on collars, or blood on remnants of hide served as evidence of a violent death. In these cases scats, tracks, wounding patterns, other signs, and season of kill (bears hibernating in winter) served to identify the predator involved (Ballard et al. 1979; Adams et al. 1989). Bears often scraped up portions of the tundra mat and buried portions of the carcass or left crushed, cleaned bones in a small area with the collar. Wolves often left the carcass intact, cached whole or half carcasses in snow or muskeg without obvious digging, or carried the bloody collar some distance from the kill site of scattered crushed bones, hair, and pieces of hide. Golden eagles (*Aquila chrysaetos*) always left long bones intact, muscle and sinew were threaded, and talon wounds were evident when significant muscle tissue remained on the sides of the calf. A collar soaked in blood indicated lynx (*Lynx canadensis*) predation.

ESTIMATING CARIBOU HARVEST

Procedures for estimating total and female caribou harvest varied, depending on the type of harvest reporting system. We considered harvest reports collected from permit hunts accurate estimates of total harvest because 97–99% of permittees responded. In addition, we added estimates of illegal harvest from road and trail surveys each year. All harvest since 1993 and most harvest during 1990–1992 was conducted under permit hunts. During general season hunts, harvest was reported by mandatory mail-in report cards without the benefit of reminder letters. Correction factors for general season hunts were derived from road surveys and surveys of transporter services during 1973. To avoid biased reporting, hunters were not told the purpose of these surveys. The surveys and subsequent mail-in harvest reports were treated as a mark–recapture sample to estimate total harvest. Harvest from general season hunts was multiplied by 1.59.

EVALUATING HERD NUTRITIONAL STATUS

We used 4 indices to evaluate relative condition/nutritional status of the herd. First, we estimated pregnancy rates and age of first reproduction during the 1992 through 1998 calving seasons, using a radiocollared sample of cows as described above. Sample sizes varied annually from 39–48 cows ≥36 months old and 5–13 cows 24 months old. Second, we annually weighed 14 or 15 female autumn calves and 44–71 newborn calves using a calibrated spring or electronic scale. Third, we estimated the median calving date during 1992–1998, which is the date that 50% of the pregnant radiocollared cows had given birth.

Last, we estimated the percent mortality of calves during their first 2 days of life. High calf mortality (e.g., 15–25%) during the first 2 days of life has been linked to malnutrition, and we evaluated this factor as an index to herd nutritional status (Whitten et al. 1992). To detect calf mortality during the first 2 days of life, we observed a sample of 32–47 radiocollared, pregnant cows on consecutive days during calving seasons from 1992 through 1998. These cows were observed each day until they gave birth and on the first 2 consecutive days after birth. During 1994–1998, we determined the cause of mortality among calves to test the hypothesis that early mortality was attributable to malnutrition.

EVALUATING THE LICHEN COMPONENT OF THE HERD'S WINTER DIET TO ASSESS RANGE CONDITION

We collected 24 fecal samples from the Fortymile herd winter ranges during January through April 1992–1996. Each sample contained 25 pellets; 1 pellet was collected from each of 25 different piles found afield (Boertje et al. 1985). Samples were analyzed at the Composition Analysis Laboratory in Fort Collins, Colorado.

Wolf Capture and Treatment

We captured 28 wolves in winter 1991–1992, 8 during winter 1992–1993, 26 during 1996–1997, and 72 during 1997–1998. Usually 2 wolves were collared per pack. Prior to November 1997, captured wolves were radiocollared and released to help us evaluate wolf movements and numbers. During winter 1997–1998, we translocated 31 wolves from the study area and radiocollared the remaining wolves. Twelve adult fertile wolves were sterilized. Blood samples and body measurements were routinely collected. Radio collars transmitted for 2–4 years (Telonics).

To immobilize wolves, we used 620–660 mg Telazol® (tiletamine HCl and zolazepam HCl, Fort Dodge Lab, Fort Dodge , Iowa, USA) and 0.2–0.4 cc propylene glycol, administered in a 3-cc dart with a 1.9-cm barbed needle. We used a long-range Cap-Chur rifle, fired from a Robinson R-22 helicopter. Darts were kept heated before deployment.

Estimating Wolf Harvest Rates in the Herd's Annual Ranges

To estimate wolf harvest rates within the respective annual ranges of the Fortymile caribou herd for the years 1992–1993 through 1997–1998, we delineated annual ranges of the herd based on monthly telemetry flights beginning 1 October. We then digitized the size of the annual ranges used by the herd and estimated wolf numbers in the respective annual caribou ranges. We estimated wolf numbers using radio collars, standard track counts, and information from local trappers and pilots (Boertje et al. 1996). Mandatory reporting forms provided information on wolf harvest locations. Regulations allowed wolf hunting from 10 August–30 April and wolf trapping from 15 October–30 April on most of the herd's annual ranges.

RESULTS AND DISCUSSION

Herd Numbers and Trend

The first systematic estimate of herd numbers occurred in 1920 when several observers counted portions of the Fortymile caribou herd crossing the Steese Highway on a 20-day autumn migration that was 60 miles wide. Murie's (1935:6) extrapolated estimate in 1920 was a "conservative" 568,000.

The low point for the herd came during 1973–1975 when we conducted the first photocensuses and only 7000 caribou remained (Valkenburg et al. 1994). Herd numbers increased during the late 1970s and 1980s at annual rates of 7–10%, reaching 23,000 caribou by 1989 (Valkenburg et al. 1994).

During this study, photocensuses indicated a fairly stable trend from 1990–1995, with approximately 22,000–23,000 caribou in the herd, followed by an increase to 31,000 by 28 June 1998 (Table 1). The increase rate was 4% between 14 June 1995 and 21 June 1996, 10% between 21 June 1996 and 26 June 1997, and 20% between 26 June 1997 and 28 June 1998. Increases were also predicted by models using 1995–1998 composition, pregnancy, and mortality data (Table 1; Appendices A, B, C and D).

TIMING, RATES, AND CAUSES OF NATURAL MORTALITY

During the combined calving seasons of 1994–1998, we observed newborn calves during 11–28 May. By the end of June 1994–1996, 40–50% of the calves were dead. Annual mortality totaled 60–65% (Figs 2–4; Table 2). No significant differences occurred during these 3 years (chi-square test of proportions, 2x3 table, $P = 0.56$). This pattern of births and deaths is similar to that found in other Interior Alaskan caribou studies (Adams et al. 1995*b*; Valkenburg 1997).

A major change occurred in 1997 when calf mortality rates declined >40% compared to the previous 3 years; this decline was statistically significant (Table 2, chi-square test of proportions, 2x2 table, $P = 0.0008$). By the end of June 1997, only 18% of the calves were dead, and the total annual mortality rate was 36% (Fig 5; Table 2). Decreased mortality in the 1997 cohort was caused by declines in predation by bears and eagles. Wolf predation did not decline significantly (Table 3). Frequent snowstorms and cool weather during the 1997 calving season provided mottled snow cover, which may have allowed caribou cows to more easily hide their newborns and increase the search effort required for predators to find calves (Bergerud and Page 1987). Calving did not appear more concentrated in 1997 compared to previous years. The 1998 data were incomplete at this writing (Table 2).

Causes of death among calves <12 months old were similar among years (Table 3). Wolves and grizzly bears were consistently the major predators. Golden eagles, black bears (*Ursus americanus*), and wolverines (*Gulo gulo*) were common minor predators. Relatively few calves died from causes other than predation (Table 3), and black bears were only significant predators in 1995 and 1998 when lingering snow above the treeline forced caribou to calve among lower elevation spruce forests.

We have ceased plans to translocate grizzly bears during this study. The Fortymile Management Plan proposed translocating grizzly bears from the calving grounds during May 2001 if increased May grizzly predation on calves compensated for expected decreased May wolf predation. However, May grizzly predation on calves did not increase in 1997 or 1998 when May wolf predation on calves declined compared to May 1994–1996 (Figs 2–5, unpubl data).

Annual wolf predation rates (25–30%) on radiocollared calves (n = 50–60) varied little among the 1994–1996 cohorts and will provide the pretreatment data needed to see if reducing wolf numbers in the treatment area can significantly reduce wolf predation. Wolf sterilizations and translocations began in November 1997 and may have slightly influenced winter survival of the 1997 cohort. Full treatment of 15 key wolf packs is expected from May 1999 through May 2001, which will provide 2 years to test whether wolf predation on calves is significantly reduced (1-tailed test) compared to the 3 pretreatment years (May 1994–May

1997). We will also test for decreasing trends in summer wolf-caused mortality. Interpretations of data will depend in part on the distribution of caribou in relation to the treatment area among the various years.

Since 1991 wolf predation was the major cause of death among caribou calves 4–12 months old and caribou >12 months old. Of the 39 calves 4–12 months old for which we determined cause of death (Oct 1991–31 Jul 1998), wolves killed 35 (90%), lynx killed 2 (5%), a wolverine killed 1 (3%), and 1 (3%) died from nonpredation. Of the 34 caribou >12 months old for which cause of death was determined (Oct 1991–31 Jul 1998), wolves killed 30 (88%), grizzly bears killed 2 (6%), and 2 (6%) died from nonpredation deaths. Most (84%) of these 73 deaths occurred during the 7 months (Oct–Apr) when snow was on the ground.

We found significantly higher mortality among caribou 4 to 16 months old compared to older caribou for the years 1993–1997 (Table 1, chi-square test of proportions, 2x2 table, P = 0.007). These data conflict with those of Davis et al. (1988) who reported similar mortality rates among >5-month-old calves, yearlings, and adults in the Delta herd.

Elevated mortality from age 4 to 16 months in the 1991 cohort (57%, n = 14, Table 1) may have been associated with inadvertent separation of calves from their dams at collaring (27 Sep–22 Oct). We darted calves and their dams simultaneously in 1991 and only 2 of 14 cow-calf pairs reunited after recovery from drugging. In 1990 and 1992 through 1997, we radiocollared calves, but not their dams, and cow-calf pairs consistently reunited. Implications of these data are that human hunting of cows with calves during autumn or early winter may reduce the survival of orphaned calves where wolves are major predators. Seven (88%) of the 8 dead calves were killed by wolves.

POPULATION MODELING

We completed 4 annual models using data on herd size, herd composition, pregnancy, and mortality to illustrate the relative importance of factors affecting the size of the Fortymile caribou herd (Figs 6–9; Appendices A, B, C and D). With certain qualifications, the models can help us understand why photocensus results changed or remained stable among years. For example, if the herd increased, was this increase caused by decreased mortality, increased productivity, or both. These models are sensitive to small, statistically insignificant changes in mortality rates, i.e., when an additional 3 among 50 caribou die and adult mortality rates change from 6–12%. Therefore, caution should be used when interpreting model output, as described below.

The first year’s model (11 May 1994–10 May 1995) indicated a fairly stable trend, i.e., the number of births almost equaled the number of deaths (Fig 6; Appendix A). This stable trend was consistent with independent late June photocensuses from 1990–1995 (Table 1). To summarize, of the 20,000 adults and yearlings and 8090 newborn calves present in May 1994, we estimate wolves killed 4190 (15%) caribou within 12 months. In contrast, grizzly bears killed 2010 (7%), other predators killed 840 (3%), hunters killed 330 (1%), and nonpredation accounted for 990 deaths (4%).

The 1995–1996 photocensus and modeling data both indicated the herd increased. We counted 900 additional caribou (23,458) on 21 June 1996 compared to 22,558 caribou on 14 June 1995. Much of this increase probably resulted from the approximately 2000 additional calves born during late May 1996 (see Herd Nutritional Indices, Weather, and Related Herd Performance for increased birth rates) compared to 1994 and 1995 (Figs 6–8; Table 1). These calves are not included in the 11 May 1995–10 May 1996 modeling data. The model indicated that about 1000 more adult caribou survived wolf predation compared to the 1994–1995 model and about 1000 more calves survived because of slightly reduced nonpredation and grizzly bear predation (Figs 6–7). However, the model inputs that resulted in increased survival were not statistically significant. For example, adult mortality decreased from 12% (6/52) during May 1994–May 1995 to 6% (3/49) during May 1995–May 1996 (Appendices A and B); these differences are not significant (chi-square test of proportions, 2x2 table, $P = 0.34$).

The 1996–1997 photocensus and modeling data also indicated the herd was increasing. We counted about 2500 additional caribou (25,912) on 27 June 1997 compared to 23,458 caribou on 21 June 1996. The most likely causes of this increase were the recruitment of additional calves born during May 1996 (Figs 6–8) and improved calf survival in May and June 1997 (see Timing, Rates, and Causes of Natural Mortality; Table 2), not changes in annual survival rates in the 1996–1997 model (Tables 1–2; Fig 8). Calf survival was significantly higher during May and June 1997, compared to the previous 3 springs (Table 2; chi-square test of proportions, 2x2 test, $P = 0.0003$). Calf survival rates in the 1996–1997 model were not significantly different from rates in the previous models (Table 2; chi-square test of proportions, 2x2 table, $P = 0.89$). Neither did survival rates of caribou older than calves differ significantly (Appendices A, B, and C; chi-square test of proportions, 2x2 table, $P = 0.46$).

The 1997–1998 photocensus and modeling data also indicated the herd was increasing (Fig 9). We counted about 5100 additional caribou (31,029) on 28 June 1998 compared to 25,910 caribou on 26 June 1997. The most likely causes of this increase were the high survival of adults (Appendix D) and 1997 calves (Table 2) and the elevated pregnancy rate in May 1998 (Table 1). Calf survival was significantly higher during 1997 compared to the previous 3 years (Table 2; chi-square test of proportions, 2x2 test, $P = 0.0008$). Both optimal environmental conditions and reduced predation contributed to this increase.

CARIBOU HARVEST

To increase social acceptance of the management plan, the Fortymile Team chose to reduce the annual harvest to 150 bulls for 5 years beginning in 1996. We illustrated the relatively minor role that harvest has recently had on herd dynamics in Figures 6–9. We have intentionally held harvests low since 1973 to encourage herd growth (Valkenburg et al. 1994). Reducing harvests from 200–500 bulls (≤2% of the herd, 1990–1995) to 150 bulls (<1% bulls, 1996–2000) will not result in the 5–10% annual rates of herd increase desired by the Fortymile Team. Estimated total annual harvest averaged 2.8% of the midsummer herd size during the 6 years before 1990. In 1990 we reduced harvest because natural mortality increased and calf:cow ratios declined (Table 1).

Following 2 hunting seasons with a quota of 150 bulls, we have observed no increase in the bull:cow ratio (Table 1). No significant increases in bull:cow ratios are expected during the next 3 years. For example, bull:cow ratios in the Fortymile herd ($\bar{x}$ = 43 bulls:100 cows, range = 36–50, 1985–1997, Table 1) are not reduced by harvest compared with ratios from the only Interior Alaska herd with no harvest in recent decades ($\bar{x}$ = 43 bulls:100 cows, range = 29–56 in the Denali herd, 1985–1997).

HERD NUTRITIONAL INDICES, WEATHER, AND RELATED HERD PERFORMANCE

We studied indices to nutritional status, weather data, and herd productivity and survival for various reasons. First, comparisons with similar data from other herds allowed us to evaluate the relative nutritional status of the Fortymile herd. Second, we wanted to identify which nutritional indices may be useful in predicting herd performance. Third, nutritional data lent insights into which weather factors are important to herd performance.

We found consistent evidence for moderate to high nutritional status in the Fortymile herd during this study when indices were compared with other Alaskan herds (Whitten et al. 1992; Valkenburg 1997). Also, several indices to nutritional status improved when the herd began to increase. Longer-term data are needed, especially during a natural decline of the Fortymile herd, to describe the potential lower levels of nutritional indices in the Fortymile ecosystem.

We found evidence of excellent nutritional status in 1996 and 1998, when pregnancy rates were ≥97%. Also a 2-year-old caribou was pregnant in 1998 (n = 13). Pregnant 2-year-old caribou are rare in Alaska; although their calves rarely survive, pregnancy in 2-year-olds signifies extremely good nutritional status (Davis et al. 1991; Valkenburg 1997).

The single evidence for malnutrition during this study was the low pregnancy rate during 1993 following the abnormally short growing season of 1992. However, this single evidence for malnutrition resulted in no strong decline in herd numbers, as occurred in the Delta and Denali herds (Table 1; Boertje et al. 1996). Many adult cows (≥3 years old) apparently did not gain sufficient fat to breed in autumn 1992. The pregnancy rate in 1993 was low in the Fortymile herd (68%; Table 1), the Delta herd (30%), the Nelchina herd (66%), and the Chisana herd (50%, Valkenburg 1993). Pregnancy rates for caribou are commonly ≥82% (Table 1; Bergerud 1980). Only 5 (42%) of 12 3-year-olds produced calves in the Fortymile herd in 1993, compared with 5 (83%) of 6 in 1994, 5 (71%) of 7 in 1995, 9 (100%) of 9 in 1996, 6 (100%) of 6 in 1997, and 9 (100%) of 9 in 1998. Only 126 snow-free days occurred in Fairbanks in 1992 compared with 160 to 199 days during the previous 19 years (Boertje et al. 1996). Snowmelt was several weeks late in spring 1992, and snowfall was several weeks early in autumn 1992.

Data from pregnancy rates probably provide indices to the previous spring/summer/autumn condition, similar to data on autumn calf weights. Data on pregnancy rates indicate caribou nutritional status was poor in autumn 1992, excellent in autumns 1995 and 1997, and average in autumns 1991, 1993, 1994, and 1996 (Table 1). Autumn calf weights have been relatively high and stable, compared to nutritionally stressed herds (Table 4; Valkenburg 1997).

Autumn calves reached relatively high weights in 1992 despite the short growing season. Only during 1997 were weights significantly higher than in all other years ($P = 0.02$ in comparing cumulative years, ANOVA, and $P = 0.001–0.056$ when comparing individual years, Student's *t*-test).

Birthweights and calving dates probably provide indices to winter and spring conditions. Low birthweights and delayed calving are thought to indicate malnutrition (Espmark 1980; Reimers et al. 1983; Skogland 1985; Adams et al. 1995*b*). Fortymile birthweights during this study were relatively high and stable, compared to nutritionally stressed herds (Table 5; Valkenburg 1997). Birthweights indicated spring nutritional status improved during 1995–1997 compared to 1994 (Table 5). Unlike data from the Denali herd, an increase in birthweights did not occur when calf mortality declined in 1997 (Tables 2 and 5; Adams et al. 1995*b*). Median calving dates indicate spring nutritional status may have improved beginning in 1994. Median calving dates were 23 May in 1992 ($n = 25$) and 22 May in 1993 ($n = 24$) compared to 18 May in 1994 ($n = 32$), 1996 ($n = 37$), and 1997 ($n = 39$), 19 May in 1998 ($n = 47$), and 20 May ($n = 28$) in 1995.

Lastly, we examined the rates (1992–1998) and causes (1994–1998) of mortality among calves during their first 2 days of life to test whether perinatal mortality in the Fortymile herd is caused primarily by nutrition-related factors, as concluded by studies of the Porcupine herd (Whitten et al. 1992). We found no convincing support for this hypothesis in the Fortymile herd. Instead, predation was the major cause of death among calves ≤2 days old in 21 (78%) of 27 cases of observing radiocollared cows or calves. Also, rates of perinatal mortality were highly variable among years and not highest in 1993 when nutritional status was low or lowest in 1996 and 1998 when pregnancy rates were high. Perinatal mortality rates observed among offspring of collared cows were 3% ($n = 30$) in 1992, 14% ($n = 28$) in 1993, 22% ($n = 32$) in 1994, 7% ($n = 28$) in 1995, 21% ($n = 38$) in 1996, 3% ($n = 35$) in 1997, and 11% ($n = 45$) in 1998. In conclusion, we do not recommend mortality rates among young Fortymile calves be used as an index to herd nutritional status. The data is difficult and expensive to collect and does not seem to be correlated with nutritional status.

Because we saw no strong decline in the Fortymile herd during 1992 when nutritional status was poor, we conclude that poor nutritional status was not as strong a factor affecting caribou numbers in the Fortymile herd as in the Delta and Denali herds (Boertje et al. 1996). Contributing factors may be that weather patterns are more continental in the Fortymile herd's range, and the Fortymile herd consumes more lichens than the Delta herd (Table 6; Valkenburg 1994).

Relatively stable herd size during 1990–1995 resulted from high adult mortality during 1989–1992 (17–40%), unusually poor pregnancy rate in 1993 (68%), and low to moderate calf:cow ratios in autumn 1989–1994 (16–30, Table 1). Annual increases in the herd since 1995 resulted from several factors, including elevated pregnancy rates in 1996 and 1998, improved adult survival rates compared to the early 1990s, and improved calf survival rates, particularly in 1997. Both optimal environmental conditions and reduced predation contributed to the herd's increase. Initiating and continuing management actions to improve caribou survival during a period of optimal weather and natural increase is opportune for the Team.

HERD DISEASES

Since 1980 we have monitored potential exposure of the Fortymile herd to 10 ungulate diseases, using blood sera collected from immobilized caribou ≥4 months old. Similar data have been collected from other herds in Alaska and the Yukon (Zarnke 1996). Few documented cases exist in which infectious diseases have had a detectable effect on caribou herds in Alaska. Brucellosis in arctic caribou herds is a notable exception (Valkenburg et al. 1996*b*, Zarnke 1996). From 1980–1995, 159 sera samples have been collected from Fortymile herd caribou. There was no evidence of exposure to *Brucella suis IV* in any of these samples.

RANGE CONDITION

Range condition was excellent during winters 1991–1992 through 1995–1996, which was evident from the high proportions ($\bar{x}$ = 80%) of lichen fragments in caribou fecal samples (Table 6). We collected samples from several different wintering areas (Fig 10). Boertje (1981) and Boertje et al. (1985) provided data showing the usefulness of fecal samples in evaluating use of lichens on winter ranges. Lichens are slower growing than vascular plants and are highly preferred and highly digestible winter forage, in contrast to mosses and evergreen shrubs (Boertje 1990). Fecal samples from overgrazed winter ranges contained reduced proportions of lichens (30–40%) and higher proportions of mosses (30–60%) or evergreen shrubs (30%) compared to values observed in this study (Table 6; Boertje et al. 1985; Valkenburg 1994).

WOLF TREATMENT AND HARVEST

The Board of Game approved nonlethal treatment of 7 wolf packs during winter 1997–1998. Treatment was completed in early April 1998, reducing the 7 packs from 61 wolves to 10 wolves (Table 7), an 84% reduction. Treatment included sterilizing the dominant pairs and translocating the remaining wolves in these 7 packs. Qualified veterinary surgeons conducted 12 sterilizations on fertile adult wolves, including vasectomies in males and tubal ligations in females to retain gonadal cycling. Nine sterilized wolves remain in the study area to date, 1 was trapped, 1 was killed by another pack, and 1 resides mostly on the perimeter of the study area. We translocated 13 subordinate adult wolves (≥2 years old) in November. These wolves were moved slightly more than 100 miles southeast to the winter range of the Nelchina herd. In April we moved 18 wolves to the Kenai Peninsula; 15 were 11-months-old and 3 were subordinate adult wolves. We expect to treat another 7 packs in winter 1998–1999 and reduce no more than 15 packs to fertility-controlled pairs during winters 1999–2000 and 2000–2001.

The Fortymile Caribou Calf Protection Program, a group of private citizens, paid $400 per wolf from a large area (33,200 km^2) including most of the Fortymile herd's range beginning winter 1995–1996 and continuing through winter 1996–1997. This $400 approximately doubled the average market value of pelts and was contributed to stimulate increased wolf harvest with the goal of increasing the Fortymile herd and associated moose and sheep populations.

To evaluate the effect of the Caribou Calf Protection Program on wolves and caribou, we compiled estimates of wolf harvest rates from within the herd's respective annual ranges for 3 years before the program and during the 2 years of the program (Table 8). We analyzed wolf harvest rates over the herd's entire annual ranges because caribou used different areas each year, especially during winters. Most of the wolf harvest occurred on caribou wintering areas rather than the summer range. We detected no substantial reductions in the autumn wolf densities during this program, although a slight decline was detected following winter 1995–1996 when 57% of the wolves were harvested (Table 8). Without substantial reductions in autumn wolf densities, annual wolf predation on caribou is not expected to decline significantly.

Sustained wolf harvest rates exceeding 28% of the autumn wolf population are expected to cause wolf population declines (Fuller 1989; Gasaway et al. 1992). However, significant increases in moose and caribou numbers have been reported only after maintaining spring wolf densities 69–85% below initial autumn wolf numbers for several years (Larsen and Ward 1995; Boertje et al. 1996). In contrast, wolf densities in the respective annual ranges of the Fortymile herd were reduced only 22–31% by harvest during winters 1992–1993 through 1996–1997, except in winter 1995–1996 (Table 8).

Sustained high harvest rates or fertility control are required to keep wolf populations below levels found in systems with little or no harvest because wolves have high reproductive and immigration rates (Larsen and Ward 1995; Boertje et al. 1996). Autumn densities of 6–8 wolves/1000 km^2 have been reported in this study area since 1985 (Table 8, Gasaway et al. 1983:58). In Denali National Park and Preserve, where little wolf harvest occurred and prey densities were similar to those in the Fortymile herd's range, Meier et al. (1995) reported autumn densities of 5–10 wolves/1000 km^2 during 1986–1992. Average autumn densities of 8 wolves/1000 km^2 were reported in 13 Alaska and Yukon study areas where wolves were lightly harvested and prey densities were similar to those in the Fortymile herd's range (Gasaway et al. 1992:36–38).

CONCLUSIONS

The Fortymile herd clearly has the potential to grow. The herd uses <30% of its historic range and nutrition is not a strong limiting factor. Predicting trends in caribou numbers is problematic. We know that a variety of factors can cause a surge or drop in numbers, stability is seldom long-term, and rapid declines can occur from the synergistic effects of adverse weather and increased predation (Boertje et al. 1996). Also, we know that continental Alaskan caribou herds have commonly remained at multiyear densities of ≤500 caribou/1000 km^2 during the last 2 decades largely because of predation (Bergerud 1980; Valkenburg et al. 1996*a*). We found exceptions where strong predator control and favorable weather occurred and where wolf predation is naturally lessened. For example, coastal caribou herds have benefited by naturally low wolf predation because of a lack of alternative prey, particularly on coastal calving areas, and because rabies also periodically reduces wolf numbers in most of coastal Alaska (Ballard and Krausman 1997). The Fortymile herd multiyear density first exceeded 500 caribou /1000 km^2 in 1998.

Assuring achievement of time-specific objectives for increased Fortymile caribou numbers will depend on actions that substantially reduce predation, presumably combined with favorable weather. Novel, experimental approaches to reducing predation have been proposed, and we are well prepared to test the effectiveness of these approaches. Numbers of wolves in 7 key wolf packs were reduced 84% in winter 1997–1998, and 5 of these packs were fertility controlled to prevent reproduction in 1998. Treatment of 15 key wolf packs is planned for winters 1999–2001, after which we hope to more clearly test the effects of treatment.

Reducing predation is a value-based socioeconomic and political decision beyond the scope of this paper. Ecological and biological issues are more easily addressed. For example, sustainable harvest of a caribou herd is ecologically sound compared to dependency on alternative livestock and agricultural industries. Past studies have shown wolf reductions can be biologically effective and sound, i.e., 1) caribou herds can grow rapidly following large reductions in wolf numbers and 2) wolf numbers can recover within a few years (Larsen and Ward 1995; Boertje et al. 1996).

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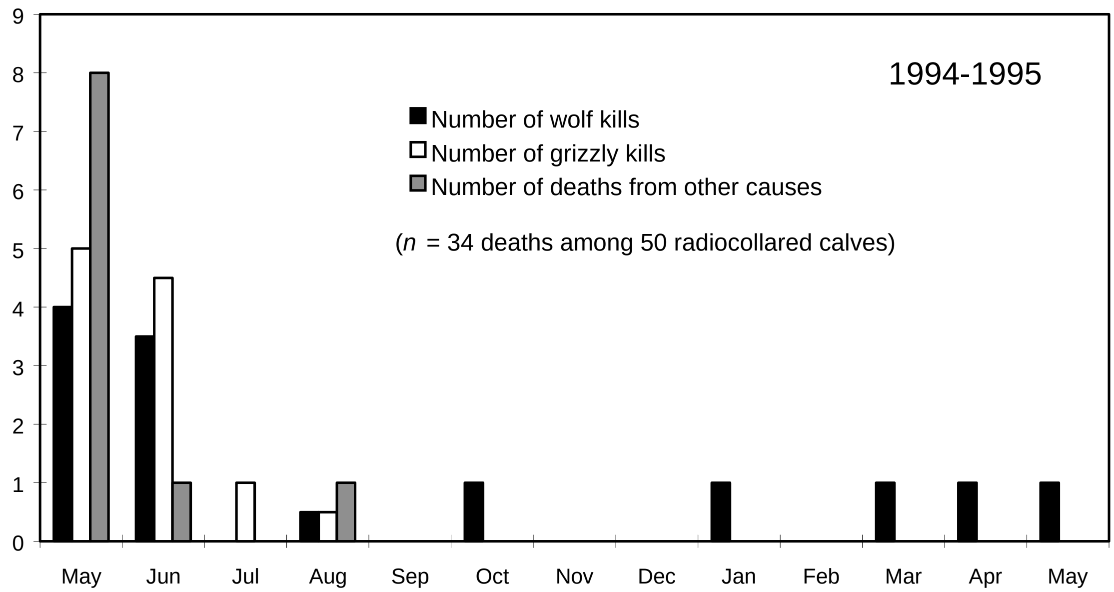

Figure 2 Frequency distribution of causes of death among 34 radiocollared caribou calves that died from May 1994 through early May 1995, Fortymile caribou herd, Eastcentral Alaska

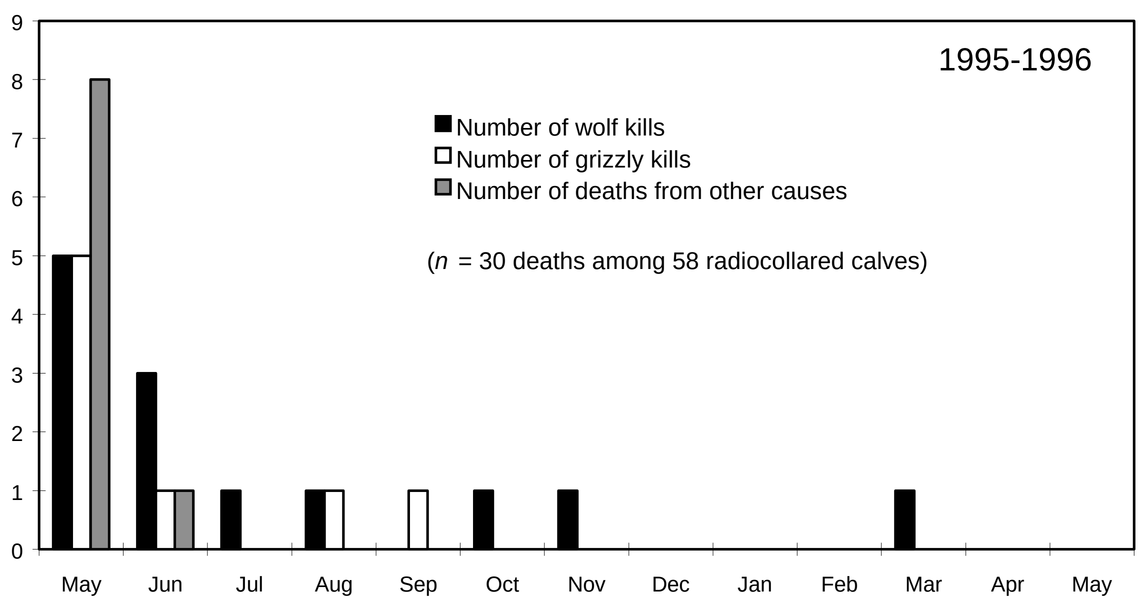

Figure 3 Frequency distribution of causes of death among 30 radiocollared caribou calves that died from May 1995 through early May 1996, Fortymile caribou herd, Eastcentral Alaska

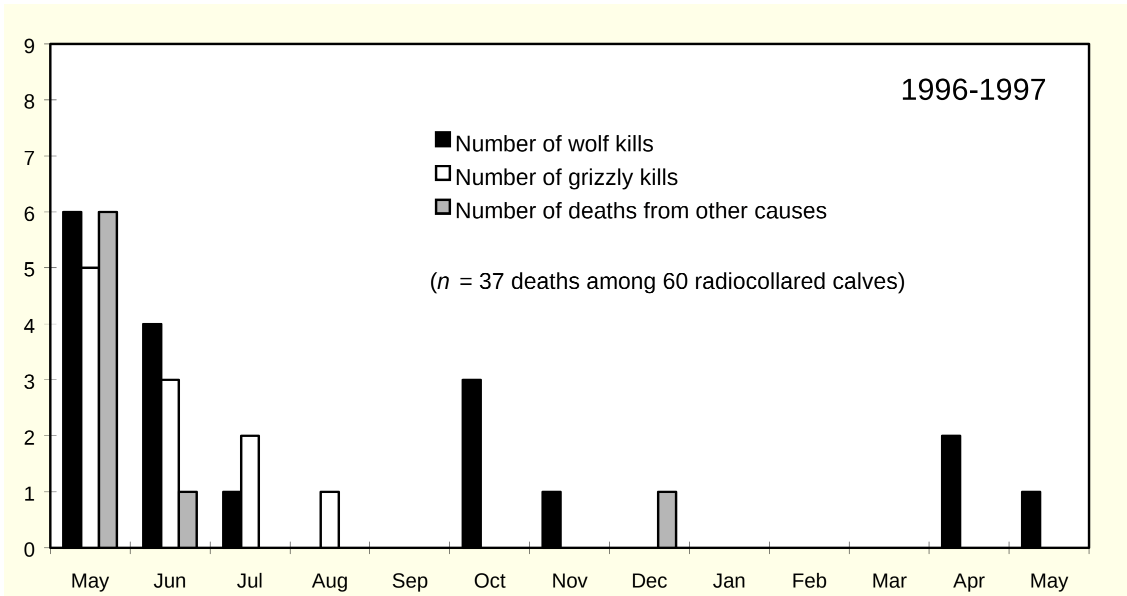

Figure 4 Frequency distribution of causes of death among 37 radiocollared caribou calves that died from May 1996 through early May 1997, Fortymile caribou herd, Eastcentral Alaska

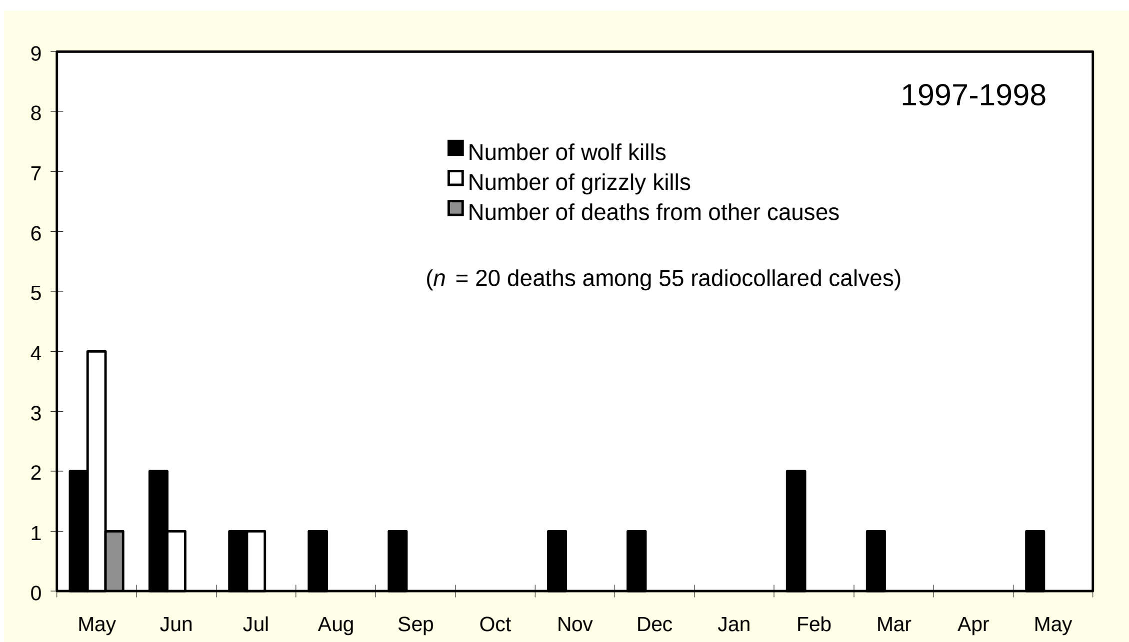

Figure 5 Frequency distribution of causes of death among 20 radiocollared caribou calves that died from May 1997 through early May 1998, Fortymile caribou herd, Eastcentral Alaska.

Figure 6 A conceptual model of births and deaths in the Fortymile herd from 11 May 1994 to 10 May 1995. Black arrows point to numbers of caribou dying from specific causes during the 12-month period, as estimated from telemetry flights and follow-up investigations of causes of death. This model independently arrived at the same conclusion as recent censuses, i.e., that herd size is nearly stable (2360 calves were recruited at the end of 12 months and 2630 adults and yearlings died during the same 12 months). Of the 8360 caribou that died during the 12-month period, wolves killed 50%, grizzly bears killed 24%, other predators killed 10%, nonpredation factors killed 12%, and hunters killed 4%. This model is derived from data in Appendix A.

Figure 7 A conceptual model of births and deaths in the Fortymile herd from 11 May 1995 to 10 May 1996. Black arrows point to numbers of caribou dying from specific causes during the 12-month period, as estimated from telemetry flights and follow-up investigations of causes of death. About 8390 calves were produced during this period and 6415 caribou died, indicating the herd increased. Of the 6415 caribou that died in the 12-month period, wolves killed 50%, grizzly bears killed 22%, other predators killed 21%, nonpredation factors killed 4%, and hunters killed 4%. This model is derived from data in Appendix B.

Figure 8 A conceptual model of births and deaths in the Fortymile herd from 11 May 1996 to 10 May 1997. Black arrows point to numbers of caribou dying from specific causes during the 12-month period, as estimated from telemetry flights and follow-up investigations of causes of death. About 10,150 calves were produced during this period and 9080 caribou died, indicating the herd increased. Of the 9080 caribou that died in the 12-month period, wolves killed 59%, grizzly bears killed 23%, other predators killed 11%, nonpredation factors killed 6%, and hunters killed 2%. This model is derived from data in Appendix C.

Figure 9 A conceptual model of births and deaths in the Fortymile herd from 11 May 1997 to 10 May 1998. Black arrows point to numbers of caribou dying from specific causes during the 12-month period, as estimated from telemetry flights and follow-up investigations of causes of death. About 9460 calves were produced during this period and 5640 caribou died, indicating the herd increased. Of the 5640 caribou that died in the 12-month period, wolves killed 68%, grizzly bears killed 24%, other predators killed 4%, nonpredation factors killed 2%, and hunters killed 3%. This model is derived from data in Appendix D.

Figure 10 Locations where caribou fecal samples were collected during January–April 1992 (2), 1993 (3), 1994 (4), 1995 (5), and 1996 (6)

Table 1 Estimated numbers, harvest, natural mortality, pregnancy rates, and composition in the Fortymile herd, 1984–1998

Year	Estimate of herd size		Estimated harvest[a] M	F	% Mortality of collared caribou 4–16 months old for year ending 1 Oct (*n*)		% Mortality of collared females 17–28 months old for year ending 1 Oct (*n*)		% Mortality of collared females ≥28 months old for year ending 1 Oct (*n*)		Pregnancy rate of collared females ≥36 months old (*n*)		Bulls or Calves:100 females Sep–Oct Bulls	Calves	(*n*)[b]
1984	13,402	(19)[c]	430	20					10	(21)	87	(23)	--	--	--
1985	--	--	421	20					9	(22)	100	(19)	50	36	(574)
1986	15,307	(19)	360	20					17	(24)	95	(21)	36	28	(842)
1987	--	--	229	20					5	(19)	95	(19)	40	37	(1274)
1988	19,975	(39)	645	150					9	(33)	95	(20)	38	30	(770)
1989	--	--	401	100					19	(27)	--	--	27	24	(1182)
1990	22,766	(16)	321	22					40	(20)	88	(16)	44	29	(1002)
1991	--	--	495	10	21	(14)			17	(12)	91	(11)	39	16	(931)
1992	21,884	(64)	432	35	57	(14)	8	(12)	17	(35)	87	(39)	48	30	(1416)
1993	--	--	335	11	8	(12)	10	(10)	10	(51)	68[d]	(47)	46	29	(2095)
1994	22,104	(91)	313	15	17	(12)	10	(10)	11	(37)	82	(45)	44	27	(1710)
1995	22,558	(85)	203	22	20	(30)	10	(10)	8	(40)	85	(41)	43	32	(1879)
1996	23,458	(97)	145	5	18	(39)	14	(7)	5	(42)	97[e]	(39)	41	36	(2601)
1997	25,910	(113)	143	8	18	(44)	9	(11)	8	(61)	85	(46)	46	41	(3313)
1998	31,029	(146)	--	--	--	--	--	--	--	--	98[e]	(48)	--	--	--

[a] From 1 Jul–30 Jun of the next year.

[b] *n*=number of females ≥1 year old classified.

[c] Number of caribou with radiocollars during census.

[d] In 1993, 5 of 12 (42%) females 3 years old were pregnant, and 27 of 36 (75%) females ≥4 years old were pregnant. Pregnancy rate in 1993 was significantly lower than rates for each of the other years on this table (chi-square test of proportions, 2x2 tables, $P \le 0.12$).

[e] Pregnancy rate in 1996 and 1998 was significantly greater than other rates during 1994–1997 (chi-square test of proportions, 2x2 tables, $P \le 0.02$).

Table 2 Timing of mortality of radiocollared calves in the Fortymile caribou herd, 1994–1998

	Radiocollared calves dying by period/Calves radiocollared in May (proportion dying, %)															
Year	May		Jun		Jul		Aug		Sep		Oct		Nov–May		Total	
1994	17/50	(34)	9/50	(18)	1/50	(2)	2/50	(4)	0/50	(0)	1/50	(2)	4/50	(8)	34/50	(68)
1995	18/52	(35)	5/52	(10)	1/52	(2)	2/52	(4)	1/52	(2)	1/52	(0)	2/52	(6)	30/52	(58)
1996	17/60	(28)	8/60	(13)	3/60	(5)	1/60	(2)	0/60	(0)	3/60	(5)	5/60	(8)	37/60	(62)
1997	7/55	(13)	3/55	(5)	2/55	(4)	1/55	(2)	1/55	(2)	0/55	(0)	6/55	(11)	20/55	(36)
1998[a]	18/72	(25)	6/72	(8)	4/72	(6)	1/72	(1)								

[a] No autumn 1998 data were available when this report was written.

Table 3 Percent annual mortality by cause among radiocollared calves in the Fortymile caribou herd, May 1994–August 1998

	Year (birth to 12 mo except in 1998)				
	Pretreatment years			Partial treatment[a]	Treatment of 7 wolf packs[b] through Aug
	1994 (n=50)	1995 (n=52)	1996 (n=60)	1997 (n=55)	1998 (n=72)
Annual percent mortality	66	58	62	36	42[c]
Percent mortality by cause:					
Wolf	26	25	30	24	11[c]
Grizzly bear	22	15	18	11	14
Eagle	6	6	8	0[d]	6
Black bear	2	8[e]	0	0	8[d]
Wolverine	2	2	2	2	1
Nonpredation[f]	8	2	3	0	1

[a] Partial treatment included translocating 13 subdominant, adult wolves in November 1997 from 4 key packs. By early April, 7 key wolf packs were reduced 84% to 10 wolves.

[b] Treatment included reducing 7 key wolf packs 84% by early April 1998 and fertility control of 5 of these packs to prevent reproduction in 1998.

[c] Through Aug only. Total annual and wolf mortality will likely increase over winter.

[d] Eagle predation in 1997 was apparently disrupted by frequent snowstorms during calving.

[e] Elevated black bear predation occurs when caribou calve below treeline. This occurs during springs with latent deep snow at higher elevations.

[f] In 1994, 3 calves broke their legs, 1 died from abandonment when its dam had no distended udder and 1 was suffocated at birth due to its large size (10.5 kg). In 1995, 1 died from a broken leg when trapped in a natural rock pit. In 1996, 1 died from abandonment when its dam had no distended udder, and 1 probably died from an unknown birth defect 48 hours after birth (no milk in stomach but dam present with distended udder). In 1998, 1 died from a bacterial infection.

Table 4 Ranked mean weights (kg) of autumn calf caribou in 11 Alaskan herds of various size and density

Herd	Year	Mean weight (kg)	$s\bar{x}$	*n*	Herd size in 1993[a]	Herd multi-year density per km^{2}[a]
Western Arctic	1994	32.4	1.3	15	450,000	1.5
	1995	36.8	1.2	9		
	1992	40.4	1.8	13		
N AK Peninsula	1995	44.7	1.6	10	18,000	0.5
	1996	46.0	2.4	10		
	1997	48.3	2.1	10		
Nelchina	1996	48.3	2.1	10	40,361	0.5
	1995	53.5	1.5	15		
	1997	55.5	1.8	10		
Chisana	1990	51.7	1.8	13	850	<0.1
Fortymile	1990	52.8	1.1	14	22,000	0.4
	1991	53.9	1.4	14		
	1994	54.5	1.2	14		
	1996	54.7	1.4	14		
	1992	55.1	1.7	14		
	1993	56.1	0.9	15		
	1995	56.7	1.1	15		
	1997	59.3	1.3	15		
Delta	1992	54.6	1.4	14	3,661	0.5
	1993	55.6	1.4	11		
	1996	55.7	1.4	14		
	1991	57.9	1.2	14		
	1997	58.2	1.0	20		
	1995	59.5	1.3	13		
	1994	59.6	1.3	15		
Macomb	1996	58.4	2.6	8	500	0.1
Wolf Mtn	1995	59.6	2.1	8	650	<0.1
White Mtn	1991	58.5	2.1	9	1000	0.1
	1995	60.6	2.1	6		
	1997	61.6	1.1	6		
Ray Mtn	1994	60.9	1.3	20	700	<0.1
Galena Mtn	1994	65.6	1.3	9	275	<0.1
	1993	66.5	3.2	4		

[a] Herd sizes and multi-year densities from Valkenburg et al. (1996) for 1993.

Table 5 Average newborn caribou weights from 8 Alaskan herds

Herd and year	Males Weight (kg)	Males $s_{\bar{x}}$ [a]	Males N	Females Weight (kg)	Females $s_{\bar{x}}$ [a]	Females N
Southern Alaska Peninsula 1989	6.70	0.67	9	5.4	0.57	9
Porcupine 1984	7.30	0.22	33	6.70	0.18	23
Porcupine 1983	7.40	0.19	24	6.60	0.16	28
Porcupine 1985	7.70	0.23	27	7.30	0.20	26
Fortymile 1994[b]	7.71	0.20	22	7.55	0.27	22
Fortymile 1998	8.41	0.13	32	8.02	0.14	39
Fortymile 1997	8.52	0.25	24	7.97	0.21	32
Fortymile 1996	8.54	0.24	26	8.09	0.17	32
Fortymile 1995	8.65	0.16	24	7.94	0.19	25
Nelchina 1996	8.26	0.24	23	7.19	0.19	17
Nelchina 1997	8.43	0.18	30	7.89	0.23	30
Nelchina 1998	8.97	0.20	30	8.57	0.18	30
Delta 1997	8.35	0.18	40	7.98	0.21	35
Delta 1996	8.39	0.23	22	7.40	0.19	28
Delta 1998	8.41	0.22	15	7.70	0.29	15
Delta 1995	8.72	0.29	26	8.31	0.24	19
Northern Alaska Peninsula 1998	8.44	0.24	19	7.17	0.30	20
Mentasta 1998[c]	8.66	0.27	15	7.98	0.32	12
Mentasta 1994[d]	8.83	0.21	18	8.09	0.19	23
Mentasta 1993[d]	8.90	0.23	15	7.91	0.20	23
Denali 1984–1987[e]	9.00	0.11	67	7.80	0.11	60
Denali 1998[c]	9.4	0.30	15	8.4	0.32	14

[a] With standard errors of about 0.2 kg, a difference in means of 0.6 kg would be significant at the P=0.05 level (Student's 2-tailed t-test).

[b] Fortymile birthweights of males (P=0.0006, t=3.51) and females (P=0.053, t=1.95) increased significantly during 1995–1998 compared with 1994.

[c] Unpubl data from L Adams.

[d] Unpubl data from K Jenkins 1996.

[e] Denali data is corrected for calf age; uncorrected weights would be 0.3–0.5 kg higher (Adams et al. 1995*a*).

Table 6 Proportions of discerned plant fragments in 24 fecal samples collected from Fortymile caribou during January–April 1992 through 1996. Collection sites are depicted in Figure 9.

Plant genus or group	Mean % ($\pm s_{\bar{x}}$) of discerned plant fragments					
	1992 *n*=6	1993 *n*=7	1994 *n*=1	1995 *n*=6	1996 *n*=4	All years *n*=24
Lichens	72 ± 9	81 ± 4	80	84 ± 3	86 ± 4	80 ± 3
Equisetum	7 ± 6	3 ± 1	6	8 ± 3	6 ± 2	6 ± 2
Mosses	9 ± 3	7 ± 2	4	1 ± <1	1 ± 1	5 ± 1
Ledum	7 ± 2	5 ± 1	5	3 ± 1	4 ± 1	5 ± 1
Graminoids	1 ± <1	1 ± <1	4	2 ± 1	2 ± 1	2 ± 1
Forbs	3 ± 2					1 ± 1
Picea	2 ± <1	2 ± <1	<1	1 ± <1	1 ± <1	1 ± <1
Dryas	1 ± 1					<1
Salix		1 ± <1		<1	<1	<1

Table 7 Wolf numbers and composition in 7 key wolf packs treated in winter 1997–1998

Pack	Autumn numbers and composition	Translocations, mortalities, and dispersal	April numbers
Granite	16 (9 adults, 7 young)	14 moved	2 sterilized adults
Butte	4 adults	1 moved, 1 killed by wolves, 1 dart mortality, 1 harvested	0
Middle Fork	9 (5 adults, 4 young)	6 moved, 1 harvested, 1 dispersed	1 sterilized adult, 1 fertile adult returned from Harper pack
Harper	11 (6 adults, 5 young)	3 moved, 6 harvested	2 sterilized adults
Wolf	8 (2 adults, 6 young)	4 moved, 2 natural mortality	2 sterilized adults
Eisen	3 adults	3 harvested	0
Tibbs	10 (5 adults, 5 young)	3 moved, 5 harvested	2 sterilized adults
Total	61	52	10

Table 8 Estimated autumn wolf numbers and harvest in the respective annual ranges of the Fortymile caribou herd, 1992–1997

	Column				
	A	B	C	D	E
Winter	Area of annual caribou range (1000 km^2)	Number of wolf packs preying on the herd (number of border packs)[a]	Estimated autumn wolf numbers in annual caribou range[b]	Wolf harvest in and adjacent to respective range	Estimated percent wolf harvest (Columns D/C x 100)
1992–1993	29.1	32 (7)	187	54	29
1993–1994	23.1	26 (6)	156	49	31
1994–1995	30.4	35 (7)	186	40	22
1995–1996	27.7	33 (7)	220[b]	126[c]	57[c]
1996–1997	35.0	37 (5)	239	68[c]	28[c]
1997–1998	30.7	37 (9)	233	59 + 31[d]=90	39[d]

[a] Border packs were packs that ranged only about 50% in the annual caribou range.

[b] Autumn wolf numbers are from the respective annual ranges of the Fortymile herd for the years beginning 1 Oct. We included only 50% of the wolves in the border packs, except in 1995–1996 when large numbers of wolves were harvested along the border. Wolves in 1995–1996 ranged in about 31,000 km^2. To account for single wolves, we added 10% to the number of wolves estimated to be in the annual range.

[c] Caribou Calf Protection Program provided a private incentive to increase harvest.

[d] Harvest totaled 59 and we translocated 31 wolves to areas outside the herd's range.

APPENDIX A Values and calculations used to model caribou population dynamics, Fortymile caribou herd, 15 May 1994–14 May 1995

Estimated parameters and calculations	Observed or calculated values
Number of cows ≥24 months old in May 1994 = percent cows in herd in October 1993 when randomly mixed (0.57) x estimated herd size in early May 1994 (20,000)	11,400
Number of 24-month-old cows in May 1994 = percent calves in herd in October 1992 (0.17) x estimated herd size in early May 1993 (20,000) x survival rate from 12 to 24 months old (0.90) x proportion of females (0.5)	1530
Number of cows ≥36 months old in May 1994 = (11,400–1530)	9870
Number of calves produced in May 1994 = (9870 x 0.82)	8090
Number of calves dying by 14 May 1995 = (8090 x 39/55)	5740
Number and cause of calf deaths, 15 May 1994–14 May 1995 (*n*=34 deaths from known causes)	
Wolf (0.382 x 5740)	2190
Grizzly bears (0.324 x 5740)	1860
Other predators (0.147 x 5740)	840
Nonpredation (0.147 x 5740)	840
Number of nonhunting deaths among caribou ≥12 months old from 15 May 1994–14 May 1995 = (20,000) (6 ÷ 52)	2310
Number and cause of nonhunting deaths among these 2310 caribou (30 adult and yearling death sites were examined from 1 Oct 1991–1 Oct 1997)	
Wolf (0.867 x 2310)	2000
Nonpredation (0.067 x 2310)	150
Grizzly bear (0.067 x 2310)	150
Annual harvest of adults and yearlings May 1994–May 1995	330
Estimated herd size 15 May 1994 (counted 22,104 on 1 July 1994 with some calves included in photos)	20,000
Estimated herd size 14 May 1995 = (20,000 + 8090 - 5740 - 2310 - 330) rounded to nearest 100	19,700
Conclusion: Herd trend approximately stable, consistent with photocensus results	

APPENDIX B Values and calculations used to model caribou population dynamics, Fortymile caribou herd, 15 May 1995–14 May 1996

Estimated parameters and calculations	Observed or calculated values
Number of cows ≥24 months old in May 1995 = percent cows in herd in October 1994 when randomly mixed (0.57) x estimated herd size in early May 1995 (20,000)	11,400
Number of 24-month-old cows in May 1995 = percent calves in herd in October 1993 (0.17) x estimated herd size in early May 1994 (20,000) x survival rate from 12 to 24 months old (0.90) x proportion of females (0.5)	1530
Number of cows ≥36 months old in May 1995 = (11,400-1530)	9870
Number of calves produced in May 1995 = (9870 x 0.85)	8390
Number of calves dying by 14 May 1996 = (8390 x 32/54)	4970
Number and cause of calf deaths, 15 May 1995–14 May 1996 (*n*=30 deaths from known causes)	
Wolf (0.433 x 4970)	2150
Grizzly bears (0.267 x 4970)	1330
Other predators (0.267 x 4970)	1330
Nonpredation (0.033 x 4970)	160
Number of nonhunting deaths among caribou ≥12 months old from 15 May 1995–14 May 1996 = (20,000) (3 ÷ 49)	1220
Number and cause of nonhunting deaths among these 1220 caribou (30 adult and yearling death sites were examined from 1 Oct 1991–1 Oct 1997)	
Wolf (0.87 x 1220)	1060
Nonpredation (0.07 x 1220)	80
Grizzly bear (0.07 x 1220)	80
Annual harvest of adults and yearlings May 1995–May 1996	225
Estimated herd size 15 May 1995 (counted 22,558 on 14 June 1995 with some calves included in photos)	20,000
Estimated herd size 14 May 1996 (20,000 + 8390 - 4970 - 1220 - 225) rounded to nearest 100	22,000
Conclusion: herd trend increasing, consistent with photocensus results	

APPENDIX C Values and calculations used to model caribou population dynamics, Fortymile caribou herd, 15 May 1996–14 May 1997

Estimated parameters and calculations	Observed or calculated values
Number of cows ≥24 months old in May 1996 = percent cows in herd in October 1995 when randomly mixed (0.57) x estimated herd size in early May 1996 (21,000)	11,970
Number of 24-month-old cows in May 1996 = percent calves in herd in October 1994 (0.16) x estimated herd size in early May 1995 (21,000) x survival rate from 12 to 24 months old (0.90) x proportion of females (0.5)	1510
Number of cows ≥36 months old in May 1996 = (11,970-1510)	10,460
Number of calves produced in May 1996 = (10,460 x 0.97)	10,150
Number of calves dying by 14 May 1997 = (10,150 x 38/61)	6320
Number and cause of calf deaths, 15 May 1996–14 May 1997 (*n*=37 deaths from known causes)	
Wolf (0.486 x 6320)	3070
Grizzly bears (0.297 x 6320)	1880
Other predators (0.162 x 6320)	1020
Nonpredation (0.054 x 6320)	340
Number of nonhunting deaths among caribou ≥12 months old from 15 May 1996–14 May 1997 = (21,000) (8 ÷ 64)	2620
Number and cause of nonhunting deaths among these 2620 caribou (30 adult and yearling death sites were examined from 1 Oct 1991–1 Oct 1997)	
Wolf (0.867 x 2620)	2270
Nonpredation (0.067 x 2620)	175
Grizzly bear (0.067 x 2620)	175
Annual harvest of adults and yearlings May 1996–May 1997	150
Estimated herd size 15 May 1996 (counted 23,458 on 21 June 1996 with some calves included in photos)	21,000
Herd size 14 May 1996 (21,000 + 10,150 - 6320 - 2620 - 150) rounded to nearest 100	22,000
Conclusion: Herd trend increasing, consistent with photocensus results	

APPENDIX D Values and calculations used to model caribou population dynamics, Fortymile caribou herd, 15 May 1997–14 May 1998

Estimated parameters and calculations	Observed or calculated values
Number of cows ≥24 months old in May 1997 = percent cows in herd in October 1996 when randomly mixed (0.57) x estimated herd size in early May 1997 (22,500)	12,830
Number of 24-month-old cows in May 1997 = percent calves in herd in October 1995 (0.18) x estimated herd size in early May 1996 (21,000) x survival rate from 12 to 24 months old (0.90) x proportion of females (0.5)	1700
Number of cows ≥36 months old in May 1997 = (12,830-1700)	11,130
Number of calves produced in May 1997 = (11,130 x 0.85)	9460
Number of calves dying by 14 May 1998 = (11,130 x 21/56)	4170
Number and cause of calf deaths, 15 May 1997–14 May 1998 (*n*=20 deaths from known causes)	
Wolf (0.65 x 4170)	2710
Grizzly bears (0.30 x 4170)	1250
Other predators (0.05 x 4170)	210
Nonpredation (0 x 4170)	0
Number of nonhunting deaths among caribou ≥12 months old from 15 May 1997–14 May 1998 = (22,500) (4 ÷ 68)	1320
Number and cause of nonhunting deaths among these 1320 caribou (30 adult and yearling death sites were examined from 1 Oct 1991–1 Oct 1997)	
Wolf (0.867 x 1320)	1140
Nonpredation (0.067 x 1320)	90
Grizzly bear (0.067 x 1320)	90
Annual harvest of adults and yearlings May 1997–May 1998	151
Estimated herd size 15 May 1997 (counted 25,910 on 26 June 1997 with some calves included in photos)	22,500
Herd size 14 May 1996 (22,500 + 9,460 - 4170 - 1320 - 151) rounded to nearest 100	26,300
Conclusion: Herd trend increasing, consistent with photocensus results	